Reusable Launch Vehicle Vertical Lander Guidance and Control Research

Dan J. Coughlin/ED13
205–544–2159

Don R. Krupp/ED13
205-544–1812

Michael W. Gallaher/ED13
205–544–1447

NASA is considering a vertical lander as a candidate concept for a single-stage-to-orbit reusable launch vehicle. This research considers three strategies for guiding and controlling the inversion of a reentering reusable launch vehicle (from a nose-first attitude to a vertical landing) and involves simulating each strategy (from a common reentry state to touchdown) using a common guidance algorithm and different controllers. Results demonstrate the characteristics that typify and distinguish each concept and help to identify peculiar problems, level of guidance and control sophistication required, feasibility concerns, and areas in which stringent subsystem requirements will be imposed by guidance and control.

The reusable launch vehicle vertical lander is envisioned to be a completely autonomous vehicle capable of performing a variety of missions, including the delivery of payload and/or personnel to the planned *International Space Station*. Investigators, serving as members of MSFC's Reusable Launch Vehicle Flight Mechanics Team, concentrated on guidance and control subsystem design and analysis for the reentry, inversion, and landing phases of the mission. A primary objective has been to investigate flight regimes and guidance and control issues not addressed by the DC–X program.

Successful design of a vertical lander spacecraft requires early attention to the vertical landing phase itself—that part of the mission which defines the lander's uniqueness. Despite the immaturity of the vertical lander configuration, preliminary simulation and analysis can yield crucial understanding of the unique challenges associated with the concept. This research has provided valuable insight into many design issues, including peculiar problem areas, the required sophistication of the guidance and control subsystem, feasibility concerns, and the subsystems likely to receive stringent requirements imposed by the guidance and control subsystem.

The vertical lander reentry and landing mission phase will consist of several distinct subphases: deorbit burns, atmospheric reentry, atmospheric flight (hypersonic to subsonic), maneuver-to-vertical landing orientation, terminal descent, and landing. Many of these phases reflect familiar, well-understood problems in space vehicles, for which engineers have established reliable approaches to solving. Other phases present unique challenges that aerospace system developers have never addressed in a functional launch vehicle—in particular, the maneuver-to-vertical orientation, terminal descent, and landing. These phases, tightly constrained by propellant and time considerations, will require closely integrated guidance and control algorithm development and implementation.

Three inversion options were investigated in this research project:

- The aerodynamic inversion concept initiates the maneuver at a "high" altitude and subsonic Mach number (as compared to the other two inversion concepts) by utilizing the vehicle's unstable aerodynamic characteristics: upon retraction of aerodynamic control surfaces, aerodynamic moments cause the vehicle to pitch up. Control torque, furnished by a reaction control system, stabilizes the vehicle in a tail-first attitude and maintains a 180-degree angle of attack until landing guidance is initiated. Upon guidance initiation, the engines ignite and the control system uses guidance commands to achieve a vertical touchdown. Figure 66 illustrates the aerodynamic inversion option.

- The propulsive inversion concept requires an inversion initiated at a lower altitude and Mach number. The vehicle allows the aerodynamic moments to cause a positive pitch (as in the previous concept, by retracting aerodynamic control surfaces and temporarily relinquishing attitude control). The vehicle ignites and gimbals the main engines to stabilize the vehicle in a tail-first attitude, while maintaining a negative flight path angle. Guidance attitude and throttle commands are then followed to touchdown.

- The powered pull-up maneuver concept begins at an even lower

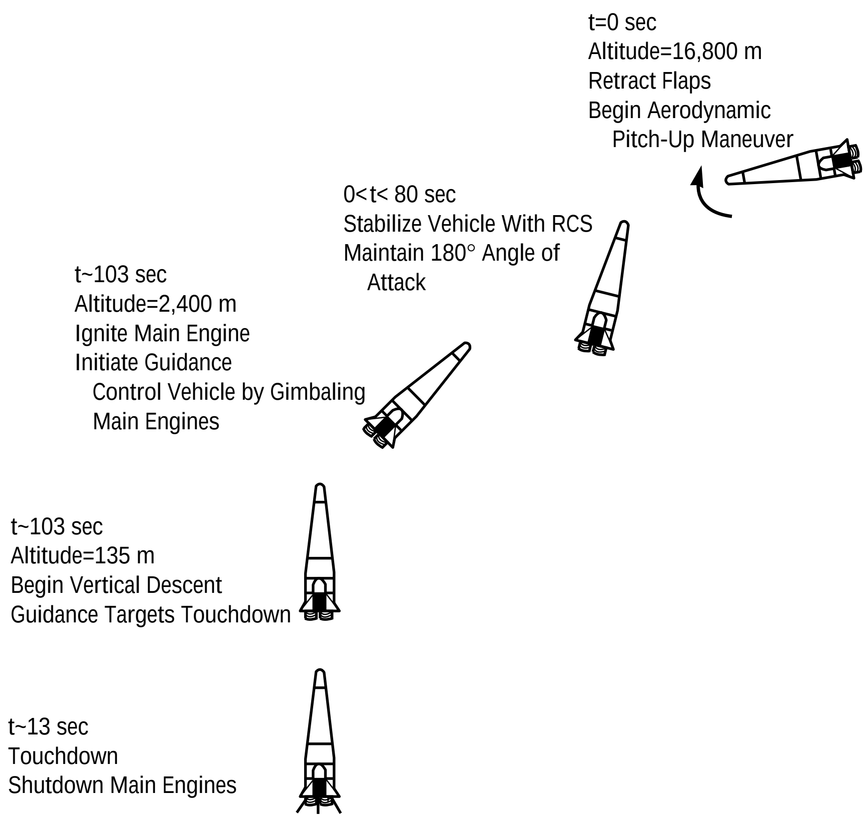

FIGURE 66.—Aerodynamic inversion maneuver.

altitude and Mach number. The main engines are then utilized to control the vehicle in a “pull-up” maneuver that raises the flight path to a positive angle (above the horizontal). This aspect of the maneuver produces a momentary “hover” point. Guidance attitude and throttle commands achieve a vertical touchdown.

Results of the guidance and control analysis indicate that no landing option investigated can be declared infeasible or precludes future analysis. In each landing scheme, a successful touchdown was achieved within the propellant budget. While each of the three simulated concepts touched down successfully, questions still remain about the controllability of this vertical lander configuration. With the current configuration (aerodynamic shape and mass properties), the aerodynamic control surfaces are inadequate to control the vehicle’s angle of attack during the reentry flight phases (especially subsonic flight). The vehicle’s shape and/or the aerodynamic control surfaces will require redesign or resizing to correct this deficiency.

The final objective of the research is to identify and discuss future analyses that would be required to establish feasibility of the vertical lander concept. Included in this list of analyses are a 6 degree-of-freedom dispersion study, engine-out analysis, and propellant management study.

Results of this research have been published as NASA Technical Memorandum 108500.

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